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NASA Facts

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Aircraft Energy Efficiency

Overview

The U.S. Air Transportation System is a multi-billion dollar industry, employing nearly a million Americans. Air transportation accounts for more than six times as many passenger miles as its nearest competitor in public transportation, the intercity bus lines.

Many aircraft in the current fleet are expected to reach the end of their nominal lifetime and require replacement in the years just ahead. The market for new aircraft is projected to be greater than $200 billion before 1990.

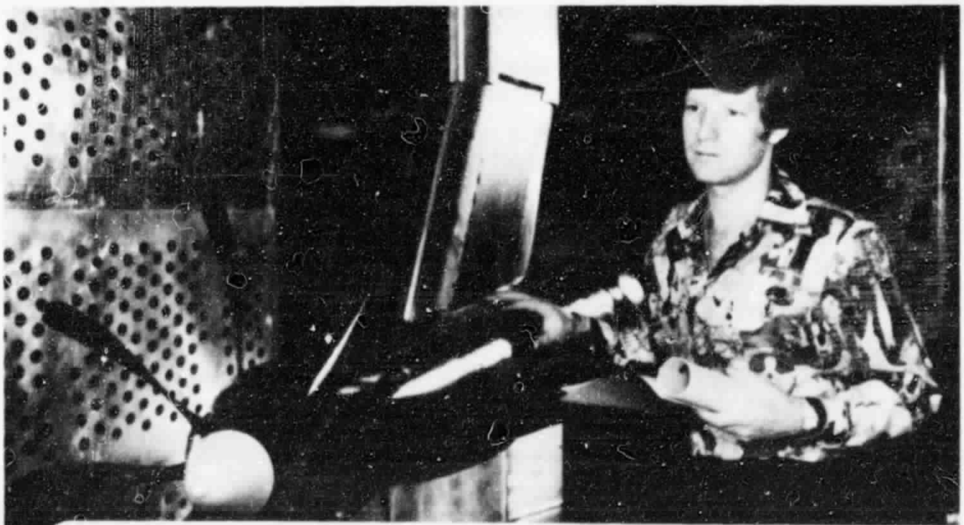
Technological superiority in aeronautics has enabled the U.S. to dominate the world aviation market, since about four of every five civil air transports in the Free World are American-made. However, foreign competitors, aided by their governments, are challenging America's market dominance.

The importance of future transport sales to the United States cannot be overstated. One jumbo jet sold abroad offsets the import of 9,000 small foreign cars. The aerospace industry is second only to agriculture in net U.S. exports, contributing to a positive trade balance of $9 billion in 1979 alone and to employment of hundreds of thousands of Americans.

One of the most serious economic problems facing air transportation today is the rapid escalation of petroleum prices. Airlines are adversely affected by the sharp rise in fuel costs. In 1973, the price of airline fuel was 12 cents per gallon. By mid-1979, it had risen to 65 cents per gallon. Fuel costs rose from 20 percent of a typical airline's operating costs in the early 1970's to about 40 percent by mid-1979.

As a result, a key consideration by airline executives in purchasing new transports is aircraft fuel efficiency. One requirement to capture a dominant share of the future air transport market is to build airplanes that give maximum miles per gallon.

Recognizing the importance of fuel efficiency and responding to a request from the U.S. Senate, NASA began an effort in 1975 to define the advanced technology needed for aircraft fuel conservation. NASA planning, with advice from industry, led to the NASA Aircraft Energy Efficiency Program.



Wind tunnel testing of 8-bladed propeller.

(NASA-Facts-96/9-80) AIRCRAFT ENERGY EFFICIENCY. OVERVIEW (National Aeronautics and Space Administration) 7 p HC A02/MF A01 CSCL 01C

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This program is composed of six advanced technology development projects that could cut fuel consumption of future civil air transports by as much as 50 percent.

These technologies and their potentials for fuel conservation are:

Technology	*Potential Reduction in Fuel Consumption**
Engine Component Improvement	5%
Advanced Energy-Efficient Engine	10–15%
Advanced Turboprops	20–40%
Composite Structures	10–20%
Aerodynamics and Active Controls	10–20%
Laminar Flow Control	20–40%

*Projected fuel savings by developing all technologies total more than the 50% combined potential. The reasons for this discrepancy are that not all technologies are applicable to every aircraft and that one technology improvement could overlap or preclude another.

Engine Component Improvement

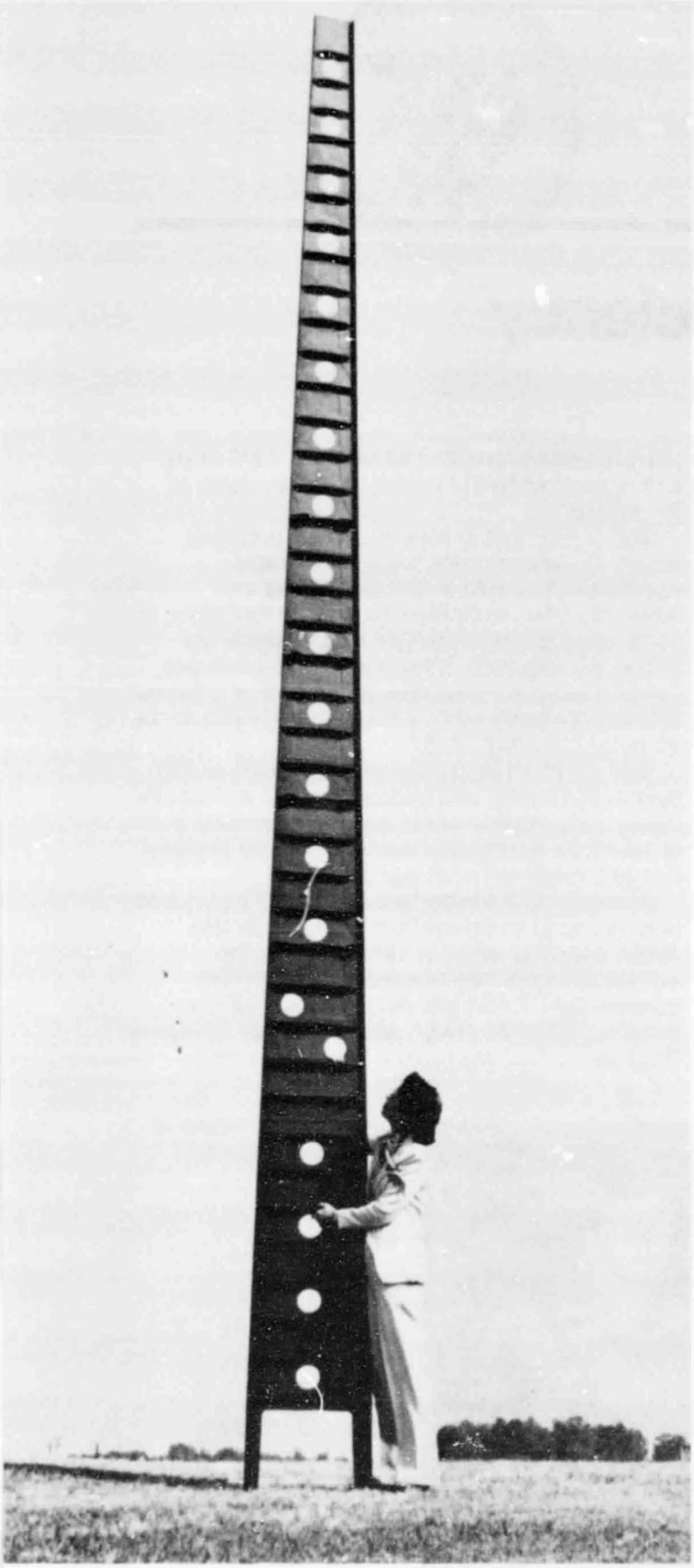
Nicked fan blades . . . worn compressor tips . . . leaking ducts and bearing seals . . . eroded turbine blades . . . warped combustors—such deterioration wastes fuel. NASA has conducted tests to determine why engine components degenerate and which impaired components waste the most fuel. It focuses its efforts on reducing deterioration of components that waste the most fuel. These improved components should be available for airline use by the early 1980's.

As an example, NASA has developed a seal for gas turbine engines that is effective under conditions severe enough to cause conventional seals to fail. The seal, referred to as the lift pad, reduces not only fuel waste but also maintenance cost.

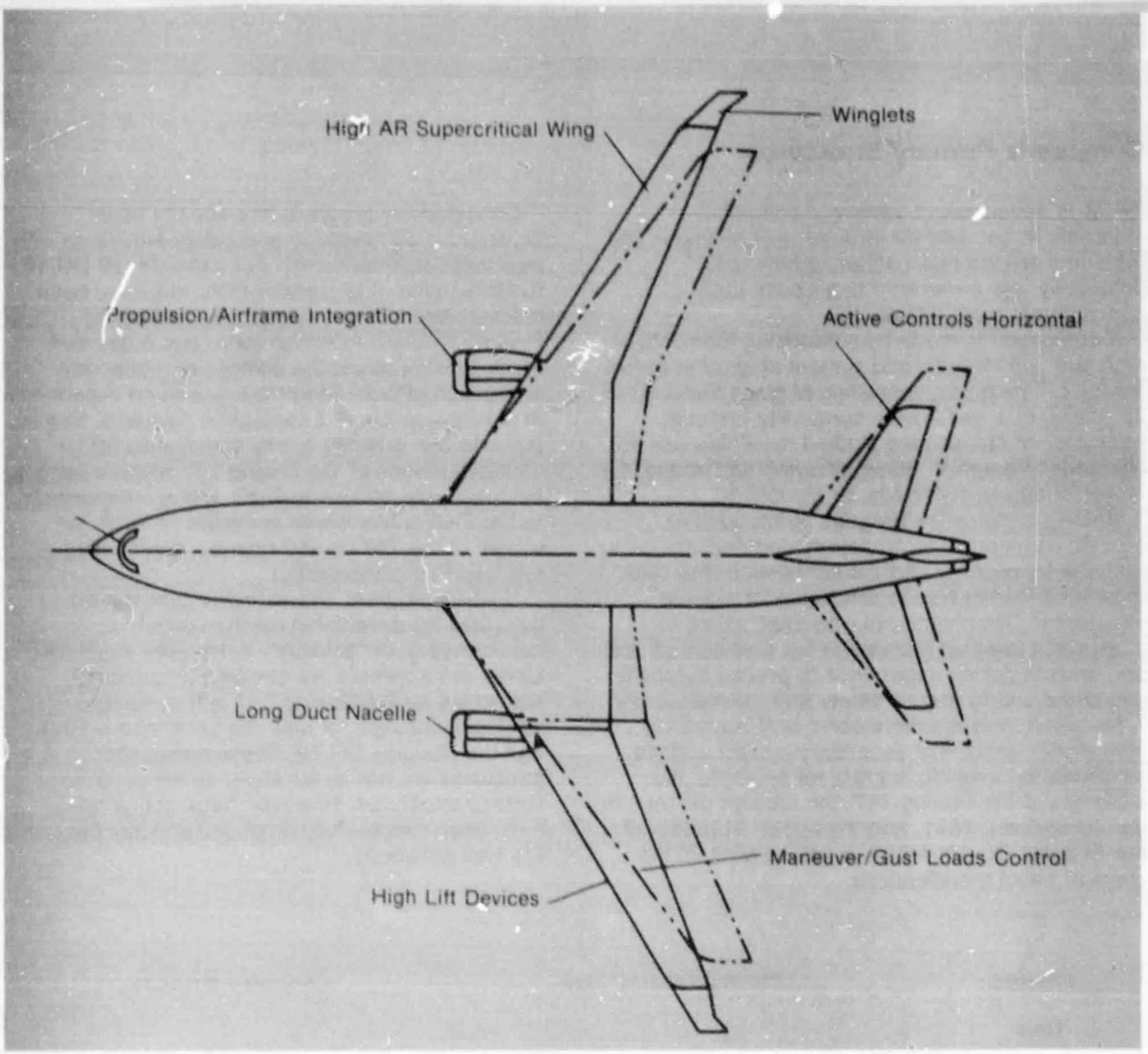
Advanced Engines

NASA is refining and applying a number of advanced fuel-saving engine concepts. Engines employing technology developed in this program are expected to be available for new aircraft scheduled for service by 1990.

One concept calls for increasing the cycle pressure ratio and turbine operating temperature of the engine with the result that a greater proportion



"Feather-light" spar developed from new lightweight materials.



NASA Energy Efficient Transport.

of the fuel is converted into energy. The major problem in this area is to develop engine structures and components that can tolerate the higher engine temperatures and pressures.

Another concept involves use of a mixer, a mechanical device that combines the duct and core streams emitted by a fan-jet engine and discharges them through a common exhaust nozzle. The duct stream is the air that passes through and is compressed by the engine fan. It exits without being burned. It generates thrust in the same way as air passing through a conventional propeller. The core stream is the air that passes through the engine turbine. It is compressed and burned with the engine fuel before exiting. Improved mixing of the two streams, that the mixer would make possible, produces more uniform exit velocities and temperatures which decrease fuel consumption.

This engine research will also lead to cleaner exhausts and lower noise.

Advanced Turboprops

In the 1950's, turboprop engines with four-bladed propellers were widely used by airlines. Airliners then cruised about 650 kilometers (400 miles) per hour at an altitude of approximately 6,000 meters (20,000 feet). Today's jets fly at about 850 kilometers (530 miles) per hour at an altitude of more than 9,000 meters (30,000 feet). They provide air travelers with a ride that is not only faster but also quieter and more comfortable than a ride with the old turboprops.

NASA is developing a new breed of turboprops that are as good as and less expensive to use than jets. For example, NASA is solving the acute noise problems that occur when propeller tips are whirling at supersonic speeds by designing thin short blades made of new high strength composite materials. The newly designed propellers come with eight or ten such blades. The new fuel-sparing turboprops could provide performance, passenger comfort, and safety comparable to jets.

Composite Primary Structures

NASA is developing a variety of composite materials to be used for structures of airliners. The materials are stronger, stiffer, lighter, and potentially less expensive to produce than conventional metal structures.

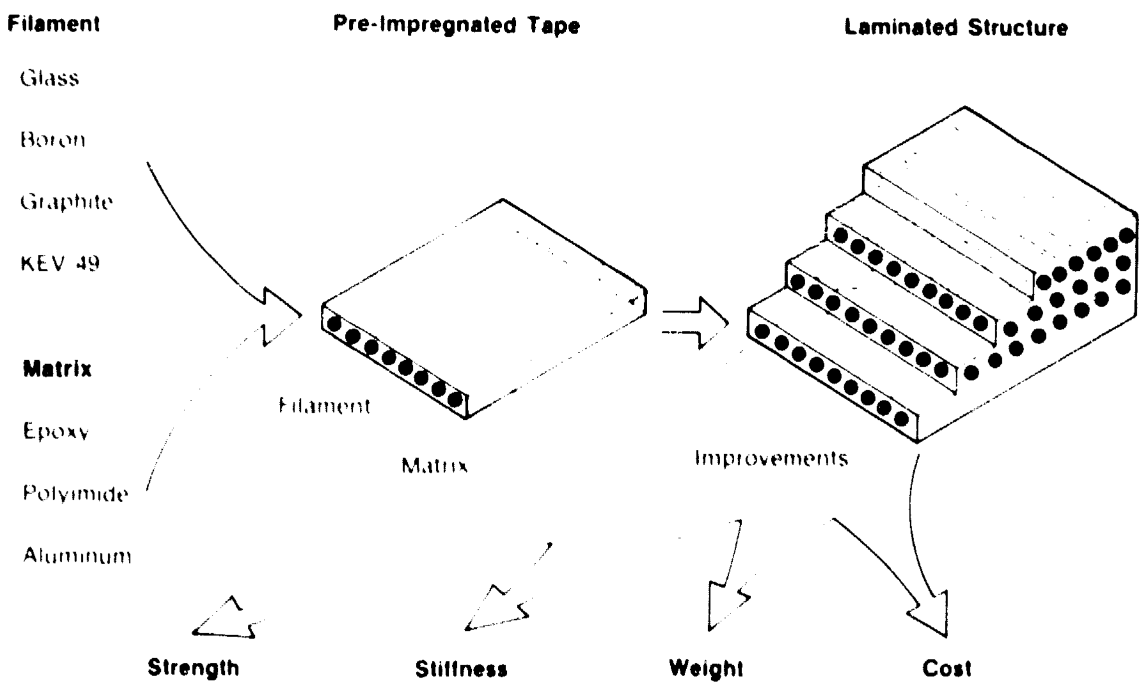
A composite is made by embedding filaments of high strength material into a sheet of another called a matrix. Fiberglass, consisting of glass filaments in an epoxy, is a well known composite material. Examples of composites studied for airline use are filaments of graphite, glass, or boron embedded in a matrix of epoxy, polyimide, or aluminum.

NASA's composites program is intended to provide commercial air transport manufacturers with both the technology and the confidence they need to commit themselves to producing composite structures. This means not only capabilities for design and low cost fabrication but also enough test and manufacturing experience to predict durability and costs and to assure safety and maintainability.

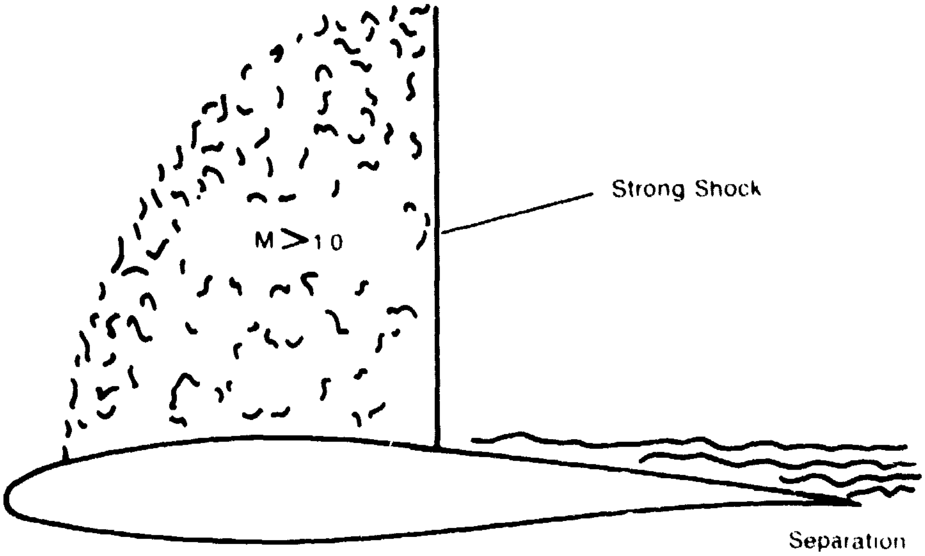
Manufacturers are developing and evaluating composite versions of secondary control surface structures on existing aircraft; for example, the elevators of the Boeing 727, the inboard ailerons of the Lockheed L-1011, and the upper aft rudder of the Douglas DC-10. NASA is paying 90% of the costs of these modifications.

Considerable progress has already been achieved in constructing secondary structures with new composite materials. For example, 20 DC-10 rudders made of composite materials have been manufactured; their designs, certified by the Federal Aviation Administration; and a decision, made to incorporate the composite rudder into production aircraft. Moreover, based on experience in developing the 727 composite elevators, Boeing plans to use graphite epoxy composites for all control surfaces of the Boeing 767 which it plans to introduce into service in 1982. Using composites rather than conventional materials reduces the weight of the 767 by 450 pounds, contributing to reduced fuel consumption.

NASA's program also includes cost-shared contracts for developing medium-sized, load-carrying, or "primary", composite structures. Under development are composite horizontal stabilizers for the Boeing 737 and composite vertical stabilizers for both the Lockheed L-1011 and the Douglas DC-10. These composite structures are not as far along as the control surface structures. However, large components have been successfully produced and test programs are well advanced.

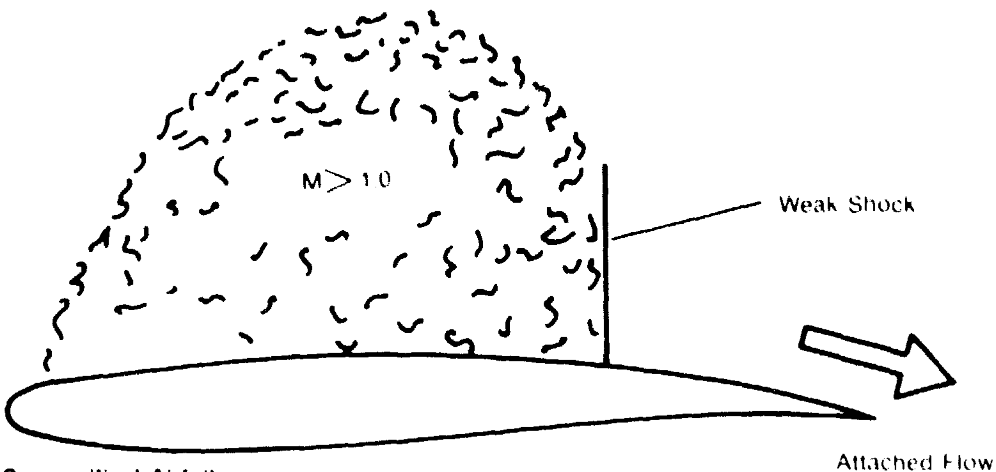


Advantages of NASA developed composite materials.



Conventional Airfoil

Comparison between conventional and supercritical airfoils shows supercritical flow phenomena.



Supercritical Airfoil

Energy Efficient Transport Program

NASA is also focussing technology development efforts on aerodynamics and active controls.

Aerodynamics covers the effects of an aircraft's detailed geometry on airflow over its surface and the forces on and motions of the aircraft that result from this airflow. For example, a shockwave develops midway along the upper part of the wing of transport aircraft at cruise speeds. This shockwave creates substantial air drag and loss of lift which reduces flight efficiency. NASA has developed and flight tested a supercritical wing so shaped that it moves the point of maximum air drag to the wing's rear. The shock wave is far less severe than on the conventional wing, and fuel efficiency is substantially improved.

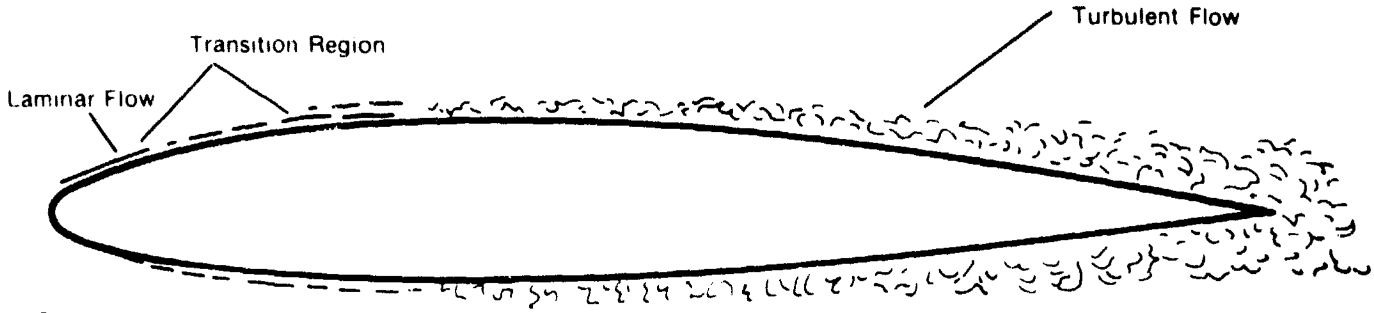
The supercritical airfoil is slightly flatter on top, curving downward at the rear. This design results in substantial air drag reduction without loss of lift.

NASA is also developing a high aspect ratio supercritical wing. A high aspect ratio wing has a long span relative to its width. Wings with high aspect ratios increase an airplane's aerodynamics efficiency, reducing its use of fuel.

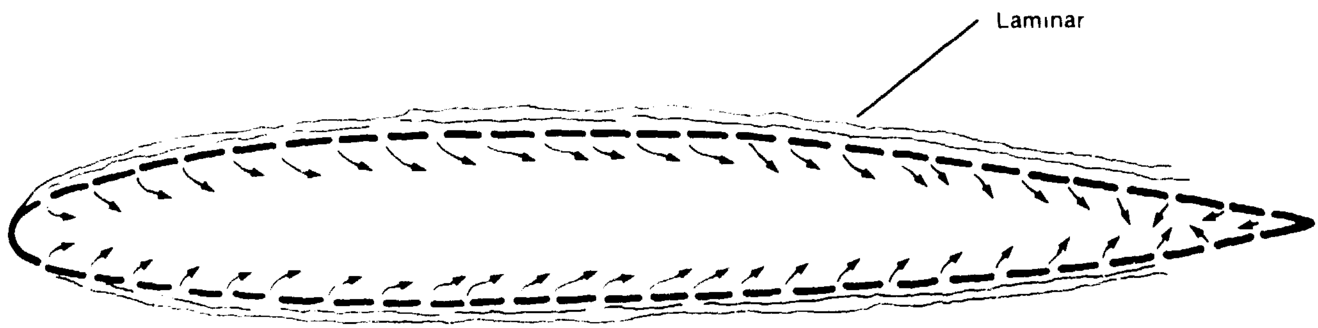
Additional increases in performance of aircraft in cruise flight are made possible by installing NASA-developed nearly-vertical winglets on wingtips of aircraft. The winglets act as lifting surfaces and reduce drag.

Both the supercritical wing and the winglets are being incorporated into future or existing aircraft. The upcoming Boeing 767 will have a supercritical wing while the existing DC-10 may eventually incorporate winglets.

The term "active controls" refers to a flight control system which links aircraft control surfaces to a computer and sensors. Active controls automatically react to limit unwanted motion or loads on the aircraft structure. Comparitively lightweight electrical wiring replaces the heavy control system of rods, hinges, and hydraulic lines that normally



Conventional Airfoil



Laminar-Flow-Control Airfoil

Reduced surface turbulence shown between conventional and "Laminar-flow-control" airfoil.

transfer the pilot's commands from the cockpit controls to wing and tail surfaces. Active controls permit reductions in sizes and weights of the wing and tail. The system's rapid response increases aircraft stability. The substantial reductions in weight made possible by active controls contribute to increased fuel efficiency.

An active control system, as an example, has been flight tested in a Lockheed L-1011. With the active control system, wing-bending stresses during maneuvers were reduced as much as 60 percent. In the L-1011 the active control system permitted the wing span to be extended an additional nine feet. The extra span increases lift and has been demonstrated to reduce fuel consumption by about 3 percent.

Other energy-saving geometry changes under investigation include modifications to the location and external shape of the nacelles (engine housings).

Laminar Flow Control

A thin sheet of flowing air, called the boundary layer, moves along the surface of a vehicle in motion. On airplanes flying well below the speed of sound, this layer flows steadily along all surfaces and is smooth or laminar.

Today's civil air transports typically cruise at about 800 kilometers (500 miles) per hour. At such a speed, the boundary layer just behind the wing's leading edge changes from laminar to turbulent, causing friction drag on the wing. This drag wastes fuel.

A concept called laminar flow control calls for removing some of the air from the surface by suction, thus maintaining laminar flow. The theory of the laminar flow control concept was demonstrated in the mid-1960's by flight tests of the U.S. Air Force X-21 experimental aircraft. However, its application was uneconomical and not easily maintainable. Providing the required surface suction is complicated by the need to vary this suction over different parts of the wing using a single pump.

The factors affecting laminar flow on which NASA is conducting research are:

A laminar-flow-controlled wing applied to a general aviation aircraft.

- The proper wing geometry, such as sweep and airfoil shape, that will also maintain the advantages of supercritical flow.
- Manufacturing processes that will economically produce geometries with the necessary stringent controls on waviness, joints, and gaps.
- The proper suction distribution and the best surface configuration to achieve it with minimum corrosion and clogging problems in the airline operational environment.
- Systems and operating procedures that will prevent the sensitive laminar boundary layer from being triggered to a turbulent state by bugs or other contaminants or by noise.

Another consideration is the weight of materials and pumping system used in laminar flow control. Advances in light-weight durable composite materials (described earlier) are expected to contribute significantly to solving this problem.

Availability and Cost

The time span of each of the six efforts described and NASA's expected expenditures, expressed in 1979 dollars, are as follows:

The $39-million engine-component-improvement program is scheduled for completion in 1980. The energy-efficient engine program, funded at $184 million, extends through 1982. The turboprop program extends through 1986, with the first phase funded at $8 million. Funding for later phases will be requested in future NASA budgets.

The energy-efficient transport program extends through 1982 at a projected cost of $80 million. The laminar flow control program, extending through 1988, is funded through the second phase, at $36 million, with later phases to be included in future budgets. The composites program, funded at $140 million, extends into 1987 if future wing and fuselage efforts are added.

Total expenditures are $451 million. The most important expected benefits, to our Nation's balance of payments in future years, are difficult to estimate. However, fuel saving alone by the year 2000 could be about a million barrels of fuel daily.

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